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Ethanol vapor prior to processing extends fresh-cut mango storage by decreasing spoilage, but does not always delay ripening☆

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Abstract

This study was undertaken to optimize ethanol vapor application as a ripening inhibitor on whole mangoes to extend fresh-cut mango shelf life. Freshly harvested mangoes were first subjected to hot water (+HW) at 46 °C for 60 or 90 min to simulate quarantine heat treatments, or remained untreated (−HW). Fruit of each batch (+ or −HW) were then held at 20–25 °C for 4 or 7 d (D4 and D7) after the hot water treatment before being exposed to ethanol vapors [0 h (E0), 10 h (E10), or 20 h (E20)]. Fruit were then peeled and cut into slices, packed in plastic clamshells, and stored at 7 °C for 15 d. Only slices from +HW-D4-E20-treated fruit maintained higher firmness, hue angle, and titratable acidity (TA) in storage. The +HW-D7-E10- or E20-treated fruit had higher hue angle than E0, but firmness, total soluble solids, TA, pH, and respiration rate did not differ. Internal ethanol and acetaldehyde were very high in slices from +HW, D4 and D7, E20 and −HW-D7-E20-treated fruit. A sensory panel could perceive higher firmness and acidity in slices from fruit treated with ethanol. However, E20 induced off-flavor, and these fruit were least preferred.

Ethanol exposure on fruit was repeated with purchased mangoes that had been subjected to a commercial quarantine heat treatment. A second heat treatment of 18 h at 38 °C and 98% relative humidity was added to one batch of fruit in this experiment. Ethanol vapors did not result in delayed ripening in those mangoes. However, this treatment inhibited microbial growth. The second heat treatment did not improve fresh-cut mango shelf life, and further, microbial growth increased compared to other treatments. It is concluded that, due to inconsistent results, ethanol vapor applied for 20 h to whole mangoes prior to processing for fresh-cut is not a practical approach to delay ripening; however, at lower doses (10 h), it could be used as a safe microbial control in a fresh-cut production sanitation system.
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Keywords: Postharvest; Fresh-cut; Mango; Ethanol; Acetaldehyde; Heat; Sensory; Microbial growth

1. Introduction

Mango imports in the U.S. have steadily increased in the last 5 years, from 115,289 MT in 1999 to 171,565 MT in 2003 (USDA, 2004), reflecting an increased consumption in the North American market. There is great interest in adding mangoes to the array of fresh-cut fruits currently available, but many technical hurdles remain for full development of this product.

One challenge when preparing fresh-cut horticultural products stems from the action of cutting plant tissue, creating a wound response, which increases the metabolic activity, leaves the tissue open to metabolite leakage, and provides an ideal support for microbial growth (Soliva-Fortuny and Martín-Belloso, 2003). Treatments that reduce physiological activity of fruit tissue may also help slow microbial growth. Low storage temperature, modified or controlled atmosphere packaging, treatments with calcium salts, antioxidants and/or enzymatic browning inhibitors, or any combination of the above were effective in prolong-

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ing shelf life of fresh-cut mangoes (Chantanawarangoon, 2000; González-Aguilar et al., 2000; Rattanapanone et al., 2001).

While the above treatments are directly applied to the cut fruit surface, the concept of reducing fruit metabolism prior to cutting is attractive since it is easier to manipulate less fragile whole fruit (Lu and Toivonen, 2000). Experiments to explore that approach have been done with apples (Lu and Toivonen, 2000; Perera et al., 2003; Bai et al., 2004), mango (Plotto et al., 2003), melon (Saftner et al., 2001), and lettuce (Saltveit, 2004). 1-Methylcyclopropene (1-MCP), a competitive ethylene action inhibitor applied to whole mangoes prior to cutting maintained firmness and light color of 'Tommy Atkins' fresh-cut pieces, but it did not delay ripening of 'Kent' (Plotto et al., 2003). The dose required to have an effect on mangoes (between 10 and 50 $\mu L\ L^{-1}$; Jiang and Joyce, 2000) is currently higher than the amount for which 1-MCP was registered for commercial applications (Agrofresh, personal communication), and its use is therefore not pursued in the current project.

Exogenous ethanol may inhibit fruit ripening (Saltviet and Mencarelli, 1988; Saltveit and Sharaf, 1992; Beaulieu and Saltveit, 1997; Ritenour et al., 1997). Ethanol vapors applied to whole apples reduced ethylene and CO_2 production of fresh-cut apples, and their shelf life was increased due to maintenance of visual quality (Bai et al., 2004). Ethanol vapors applied to whole 'Kent' mangoes for 24 h also maintained higher firmness, visual quality, and lower sugar levels in fresh-cut pieces (Plotto et al., 2003). However, a secondary effect of these treatments was the perception of undesirable flavor notes in fruit tissue when exposed to ethanol for 24 h (Bai et al., 2004; Plotto et al., 2003), but no detrimental flavor was perceived when exposure time was reduced to 8 h (Plotto et al., 2003). Another secondary effect of ethanol observed in previous experiments was the absence of decay on fresh-cut mangoes after 2 weeks in storage at 7 °C, in comparison with the control and other treatments (Plotto et al., unpublished observations). Ethanol dips have been reported to control postharvest decay of cherry (Karalabut et al., 2004), grape (Litcher et al., 2002), peaches and nectarines (Margosan et al., 1997). Therefore, the question was asked whether ethanol vapor could have a similar effect on microbial control of fresh-cut slices.

Most mangoes available in the U.S. are imported and are required to be subjected to a quarantine heat treatment to prevent introduction of the Mediterranean fruit fly *Ceratitis capitata*, and Mexican fruit fly *Anastrepha* spp., *Anastrepha ludens* (USDA-APHIS, 2002). The protocol adopted in most countries of Central and South America consists of a single dip in water at 46 °C for 65–90 min, depending on fruit size. In general, such water baths tend to synchronize and accelerate ripening (Jacobi et al., 2001), although temporary but reversible reductions in 1-aminocyclopropane-1-carboxylate (ACC) oxidase activity (Mitcham and McDonald, 1997) and ethylene production (Ketsa et al., 1999) were reported.

The objectives of this study were to optimize ethanol vapor applications to whole Florida-grown mangoes, cv. 'Kent', prior to fresh-cut processing by additionally investigating the effects of a postharvest quarantine heat treatment and ripeness stage at the time of ethanol application on slice storability and quality. Since imported mangoes are most likely to be used by a commercial facility for fresh-cut processing, ethanol treatments were repeated on imported, hot water treated Peruvian 'Kent' mangoes, with a vapor heat treatment added to evaluate the effect of residual ethanol or heat on microbial stability of the fresh-cut fruit.

2. Materials and methods

2.1. Treatments

'Kent' mangoes were harvested from a commercial farm in Homestead (Florida) and brought to the USDA-Citrus and Subtropical Products Laboratory. Fruit were pre-washed in 2.0 mM (150 mg kg^{-1}) sodium hypochlorite (commercial bleach) to remove dirt and latex, and were sorted by weight. Two days after harvest, washed fruit were taken to the University of Florida for hot water treatments: Half of the fruit received the quarantine hot water treatment following the USDA treatment schedule (USDA-APHIS, 2002). Mangoes were placed in water at 46 ± 2 °C (+HW) for 90 min or 60 min for fruit with weights greater than 500 g (80% of the fruit) or less than 500 g (20% of the fruit), respectively. Untreated fruit (−HW) were maintained at room temperature (25 °C). Ripeness stage at the time of quarantine heat treatment, 2 d after harvest, was RS1 (green) and RS2 (fruit hard, well formed, with slight blush) per Miller classification (Miller et al., 1986). Following HW treatment the fruit were held at 20–25 °C and 60–80% RH for up to 7 d prior to ethanol treatment.

The first ethanol treatment was initiated 4 d after the HW treatment (+HW-D4). Fruit at that time were at the RS3 ripeness stage (firm, well formed, with some yellow color development) for the +HW-treated mangoes, and at the RS1–RS2 ripeness stages for the controls (−HW-D4) (Table 1). The second ethanol treatment was initiated 7 days after HW treatment (+HW-D7). Heat-treated fruit were then at the RS4 ripeness stage (fairly firm, with some yellow ground color development; Miller et al., 1986), while non-heated fruit (−HW-D7) ranged from RS2 to RS4, with most of the fruit at RS4 (Table 1).

Ethanol treatments were applied at 20–25 °C. Twelve fruit per replication were placed in 19 L plastic buckets, with a beaker containing an initial 5.0 g ethanol (200 proof U.S.P., Millennium Petrochemicals, Inc., Tuscola, IL) per kilogram of fruit, and a filter paper wick to aid evaporation. Buckets were closed tightly and fruit allowed to absorb ethanol for 10 h (E10) or 20 h (E20). Control (E0) fruit were placed in buckets under the same conditions as E20, but without ethanol. There were three buckets per treatment, each rep-

Table 1
Treatments, initial time of ethanol treatment after hot water (HW) treatment (4 or 7 d, D4 and D7, respectively), ripeness stage and ripeness description at the time of ethanol treatment, and amount of ethanol absorbed by 'Kent' mangoes during each treatment

Quarantine treatment[a]	Days after HW	Ethanol treatment[b]	Ripeness stage[c]	Ripeness description[c]	Absorbed ethanol ($g\,kg^{-1}$)
Harvested mangoes					
+HW	D4	E10	RS3	Firm, well formed, some yellow	1.11 ± 10.16
		E20			1.73 ± 0.05
	D7	E10	RS4	Fairly firm, some yellow ground color	1.15 ± 0.12
		E20			1.54 ± 0.22
−HW	D4	E10	RS1–RS2	Hard, green with slight blush	0.84 ± 0.53
		E20			1.08 ± 1.04
	D7	E10	RS2–RS4	From slight blush to yellow ground color	1.83 ± 0.48
		E20			1.96 ± 0.15
Store-purchased mangoes					
+HW	Unknown	E10	RS3–RS4	Firm to fairly firm, yellow ground color	1.72 ± 0.16
		E20			3.15 ± 0.08

[a] For harvested mangoes, +HW: $46 \pm 2\,^{\circ}C$ water bath for 90 min (fruit greater than 500 g) or 60 min (fruit less than 500 g); −HW: no hot water bath. For store-purchased mangoes, conditions of HW treatment were assumed to follow USDA APHIS schedule.
[b] E10 and E20: fruit exposure to ethanol vapor for 10 and 20 h, respectively.
[c] Miller et al. (1986).

resenting a replication. After the end of the first and second ethanol treatments the fruit were held at 20–25 °C for 2 d and 24 h, respectively, before being processed for fresh-cut.

Ethanol treatments were repeated with store-purchased 'Kent' mangoes imported from Peru. Fruit were exposed to ethanol for 10 or 20 h as described previously when they were at the RS3 and RS4 ripeness stages (Table 1). After treatment, fruit were transferred to 15 °C storage until processing 24 h later. Additionally, one batch of fruit was exposed to 38 °C and >98% RH air (vapor heat, VH) for 18 h in a controlled relative humidity chamber (Vapor Temp®, General Signal, Blue Island, IL).

2.2. Fresh-cut process

Whole fruit were sanitized for 2 min in a solution of 5.4 mM ($400\,mg\,kg^{-1}$) sodium hypochlorite adjusted to pH 6.5 with a 2 M citric acid solution. Before cutting, fruit firmness was measured with a FT-327 fruit pressure tester (Wilson, Yakima, WA) mounted on a drill stand and equipped with an 11 mm probe. Fruit were peeled, halved, and each half cut into three longitudinal slices. Slices were dipped in an aqueous solution of 0.08 mM ($5\,mg\,kg^{-1}$) chlorine dioxide (ClO_2, Aquamira, Bellingham, WA) for 30 s, then in a solution of 51 mM (2%) calcium ascorbate (Fluka Biochemika, Buchs, Switzerland) and 52 mM (1%) citric acid (Aldrich Chemical Company, Inc., Milwaukee, WI) for 30 s. These treatments were used as effective antimicrobial (chlorine dioxide), and anti-browning (citric acid with calcium ascorbate) agents on fresh-cut mangoes in previous experiments (Plotto et al., 2003). After dipping, fruit pieces were drained, then randomly distributed in 980 mL (550 mL bottom, 430 mL top, with a hinged lid and snap closure) polystyrene clamshell containers (CI18-1160 ClearView® SmartLock®, Pactiv Corp., Lake Forest, IL), with five to seven slices per container (approximately 150–300 g). Cutting was performed in a 5–7 °C cold room, sanitizing and dip treatments were at 5 °C, and fresh-cut pieces stored for 2 weeks at 7 °C in clamshells.

2.3. Quality parameters

Fresh-cut mangoes were evaluated every 4 d after cutting for the Florida-grown fruit, and every 7 d for the store-purchased fruit. Three replicate clamshells were sampled for each treatment/day, and one measurement was taken from the pooled slices in each clamshell for most readings except for color and firmness, which were measured on individual slices.

Ethylene and CO_2 production were measured by sampling 5 mL headspace of 100–300 g mango slices from each clamshell incubated for 1 h in 1 L sealed mason jars at 7 °C. CO_2 production ($\mu g\,kg^{-1}\,s^{-1}$) was measured in duplicate on a HP 5890 (Agilent Technologies, Palo Alto, CA) gas chromatograph (GC) equipped with a thermal conductivity detector (TCD) and a CTR 1 column (1.8 m × 0.32 cm) packed with porous polymer mixture (Alltech Associates Inc., Deerfield, IL). Conditions of the run were isothermal (73 °C), helium flow at $1.3\,mL\,s^{-1}$, injection via a 167 μL loop. Ethylene was measured on a Varian CP 3800 GC equipped with a flame ionization detector (FID) and an activated alumina column. Oven, injector, and detector temperatures were 90, 70, and 250 °C, respectively. Injection volume was 1 mL gas.

Slice surface color was measured with a Minolta CR-300 Chroma Meter (Minolta, Tokyo, Japan) calibrated to a white plate using the CIE L^*, a^*, and b^* system. Slice firmness was determined using a XT2i texture analyzer (Stable Micro Systems, Surrey, England), calibrated with a 5-kg mass and equipped with a 1-cm diameter probe. The insert distance

was 5.0 mm, with a stroke speed of 5.0 mm s^{-1}. For color and firmness, two measurements were taken on each of the five mango slices in each clamshell.

After firmness and color measurements, pieces were homogenized with 1 mL water per gram of fruit tissue for 75 s, and frozen at −20 °C for sugar and acids analysis, or flash frozen in liquid nitrogen and stored at −80 °C for volatile analysis. The supernatant of thawed homogenates, centrifuged at 12,100 × *g* for 10 min, was analyzed for titratable acidity (TA), pH, and total soluble solids (SSC). For TA, a 10-mL sample of the supernatant was titrated with 0.1N NaOH to a pH 8.1 endpoint using an Orion 950 titrator (Thermo Electron Corporation, Beverly, MA). Soluble solids were determined with a digital ATAGO PR-101 refractometer (Atago Co, Ltd., Tokyo, Japan).

Volatile compounds, from 2 mL homogenate in 6-mL glass vials, with 1 mL headspace injected in the GC, were analyzed with a Perkin Elmer 8500 GC equipped with a 0.53 mm × 30 m, 1.0 μm film thickness, polar Stabilwax column (Restek, Bellefonte, PA) and a FID (Malundo et al., 1997). Volatiles of the store-purchased mangoes (3 mL homogenate in 10-mL glass vials) were analyzed with an Agilent 6890N GC equipped with and FID and same column as above, as well as with a Gerstel MPS2 autosampler (Gerstel, Baltimore, MD). Volatiles were quantified using calibration curves obtained from deodorized mango homogenate, where volatiles are first removed by rotary evaporation (Malundo et al., 1997), then spiked with five levels of authentic standards (Sigma-Aldrich, St. Louis, MO).

One clamshell from each treatment was set aside for daily visual evaluation. The overall quality was rated on a 1–5 visual scale, where "5" is excellent, "3" acceptable (lower limit for shelf life), and "1" unacceptable.

2.4. Sensory analysis

Sixteen to 18 members of the laboratory staff performed sensory evaluation of mango slices on the day they were cut, and after 6 d in storage. Each treatment was served as four 2.5-cm cubes of mangoes in a 120 mL plastic soufflé cup with a lid (SOLO® Cup Company, Urbana, IL), coded with a 3-digit random number, and presented in a randomized order. For D4-ethanol-treated fruit, panelists were presented with three samples: E0 (control), E10 and E20, 0 and 6 d in storage (+HW), or 6 d in storage (−HW). For D7-ethanol-treated fruit, panelists were presented with four samples: +HW-E0, +HW-E10, −HW-E0, and −HW-E10, 0 and 6 d in storage. A ranking test (Meilgaard et al., 1991) was performed where panelists were asked to rank overall preference, firmness, tartness, and mango flavor intensities. Additionally, panelists were asked if they could perceive any off-flavor. The taste panel took place in individual booths under red lighting. Unsalted crackers and spring water were provided to panelists to rinse their mouth between samples. The test was repeated with store-purchased mangoes.

2.5. Microbial assays

Cut fruit from store-purchased mangoes were assayed for microbial growth. Three or four representative fruit pieces per clamshell were taken from each experimental group and placed in sterile 950 mL sampling bags (Fisherbrand, Fisher Scientific, Pittsburgh, PA), one bag for each clamshell. The fruit pieces were weighed so results could be reported in colony-forming units (cfu) per kilogram. After weighing, 99 mL of sterile phosphate buffer was added to the bags and the fruit pieces were gently agitated for 2 min. Small aliquots of buffer (∼5 mL) were then taken in triplicates from the bags and analyzed on a Whitley Automatic Spiral Plater (DW Scientific, Ltd., Shipley, West Yorkshire, UK). Isolations of microorganisms from the fruit pieces were made using two types of media; plate count agar (PCA), a standard methods agar for the isolation of bacteria, and potato dextrose agar (PDA) for the isolation of more acidophilic yeasts and molds. Agars were BD/Difco Brand (Fisher Scientific). The plates were incubated at 35 °C for 48 h and the results were read on a ProtoCOL colony counter (Synoptics, Ltd., Cambridge, UK).

2.6. Statistical analyses

Quality parameters were analyzed using the SAS (SAS System Software Version 9.1, SAS Institute, Cary, NC) general linear model procedure (PROC GLM) (SAS, 1999). The experimental design was a 2 × 2 × 3 factorial structure: + or −HW, D4 or D7, and three ethanol levels, with three replications. Because of interactions between treatments, separation of means were performed only between ethanol treatments within each heat, day-of-ethanol-treatment after HW, and day-in-storage, with the LSD test, $\alpha = 0.05$. The repeat experiment with store-purchased mangoes was analyzed as a completely randomized design with four treatments (control, E10, E20, +VH). Sensory data were analyzed by using the Friedman-type statistic test for rank data, with the non-parametric analog to Fisher's LSD for rank sums (Meilgaard et al., 1991). In that test, the null hypothesis of no sample differences at the α-level of significance is rejected if the value of T in the following equation exceed $\chi^2_{\alpha,t-1}$:

$$T = \left([12/bt(t+1)] \sum_{j=1}^{t} x_{\cdot j}^2 \right) - 3b(t+1)$$

where b is the number of panelists, t the number of samples, and x_j is the rank sum of sample j. If the χ^2-statistics is significant, the non-parametric analog to Fisher's LSD for rank sums from a complete randomized block design is $\mathrm{LSD}_{\mathrm{rank}} = t_{a/2,\infty}\sqrt{bt(t+1)/6}$.

Microbial counts were analyzed with the non-parametric one-way ANOVA using the NPAR1WAY SAS procedure, and using the Savage one-way test option (SAS, 1999).

3. Results

3.1. Experiment 1: harvested mangoes

3.1.1. Whole fruit quality

Hue angle was lower for +HW (106–109) than −HW (115–116) fruit in the D4 group except for +HW-D4-E20 (114). A hue angle between 110° and 120° indicates a dominance of green color, while hue angle closer to 90° indicates more yellow, and even some red. Therefore, lower hue angle in +HW-D4 ethanol-treated fruit in comparison with −HW-D4 fruit was due to skin yellowing (enhanced ripening). However, +HW-D4, E20-treated fruit had hue angle comparable to −HW-D4 fruit, indicating that ethanol vapors for 20 h could counteract the effect of +HW. Values were within the same range for +HW-D7 (98–100) and −HW-D7 (97–102). Firmness was also higher for +HW-D4-E20 (21 N) compared to E0 and E10 (18 and 15 N, respectively), and was as high as for fruit in the −HW-D4 ethanol-treated group (20–25 N), indicating less advanced ripening. Fruit at the D7 ripeness stage had firmness ranges of 13–16 N (+HW), and 18–20 N (−HW).

3.1.2. Fresh-cut fruit physico-chemical measurements

The effects of day after HW treatment and ethanol on mango slice quality parameters were highly significant ($P < 0.001$), except for SSC, CO_2, and β-pinene (day effect only) (Table 2). Specifically, the *F*-value was much higher for the effect of day than ethanol or HW treatments for hue angle, TA and pH, indicating a strong effect of fruit ripeness at the time of ethanol treatment (day) on these variables. *F*-values were higher due to the effect of storage for firmness and L^*. Internal acetaldehyde, ethanol, and β-pinene had the highest *F*-values due to the ethanol treatment effect.

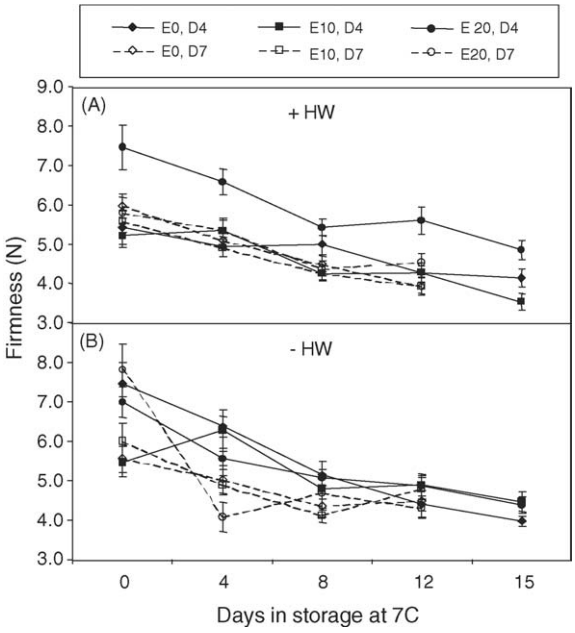

Fig. 1. Fresh-cut 'Kent' mango firmness over time in storage at 7 °C. Whole mangoes were first subjected to a quarantine hot water treatment (+HW, A) or not treated with HW (−HW, B), then treated with ethanol vapors for 0 (E0), 10 (E10) or 20 (E20) h, at two ripeness stages, 4 d (D4) or 7 d (D7) after HW treatment. Each point is the mean of 30 measurements (10 measurements per replication, 3 replications), with standard errors.

Firmness of fresh-cut mangoes decreased in storage (Fig. 1). Among +HW fruit, those subjected to E20 at D4 maintained higher firmness throughout storage (Fig. 1A). There was much more variation in the −HW group: initially,

Table 2
ANOVA tables for quality parameters of fresh-cut 'Kent' mango in storage

Source of variation	d.f.	*F*-value										
		Firmness	L^*	Hue angle	SSC	TA	pH	CO_2	Acetaldehyde	Ethanol	Methanol	β-Pinene
Heat (H)	1	4.97*	32.22***	6.65**	0.20 ns	1.43 ns	13.34***	0.13 ns	0.35 ns	3.58 ns	9.05**	0.12 ns
Day (D)	1	33.93***	88.31***	296.95***	2.62 ns	119.42***	217.29***	2.00 ns	51.78***	47.70***	13.18***	1.11 ns
Ethanol (E)	2	14.90***	10.48***	62.38***	2.33 ns	39.41***	44.62***	0.42 ns	104.30***	76.92***	11.23***	11.24***
Storage (S)	4	74.43***	253.86***	141.13***	2.68*	29.91***	32.88***	9.77***	12.14***	1.13 ns	7.04***	0.57 ns
H × D	1	0.58 ns	4.18*	6.33*	0.80 ns	0.28 ns	6.65*	0.08 ns	9.95**	2.16 ns	0.55 ns	8.35**
H × E	2	5.86**	10.93***	1.83 ns	0.53 ns	1.26 ns	2.96 ns	1.50 ns	1.45 ns	0.76 ns	0.83 ns	1.51 ns
D × E	2	3.22*	13.34***	4.96**	3.56*	4.42*	1.87 ns	0.91 ns	10.25***	26.25***	2.07 ns	1.26 ns
H × S	4	2.08 ns	5.69***	1.62 ns	2.48*	1.59 ns	5.59***	4.51**	2.04 ns	1.54 ns	2.10 ns	0.75 ns
D × S	3	3.03*	15.17***	27.06***	0.39 ns	1.99 ns	0.29 ns	0.89 ns	2.47 ns	0.86 ns	1.88 ns	0.89 ns
E × S	8	3.36***	1.39 ns	2.15*	0.93 ns	2.22*	0.43 ns	3.53**	1.45 ns	1.78 ns	0.99 ns	0.82 ns
H × D × E	2	8.22***	1.55 ns	7.21***	0.44 ns	6.58**	4.21*	1.20 ns	6.85**	2.84 ns	0.80 ns	1.78 ns
H × D × S	3	2.29 ns	7.74***	1.71 ns	0.86 ns	2.41 ns	0.92 ns	0.56 ns	1.36 ns	0.60 ns	1.65 ns	1.15 ns
H × E × S	8	2.89**	4.09***	2.66**	0.81 ns	0.78 ns	1.55 ns	0.25 ns	1.09 ns	0.81 ns	1.08 ns	0.22 ns
D × E × S	6	1.17 ns	1.42 ns	0.97 ns	0.48 ns	0.46 ns	0.18 ns	0.75 ns	0.78 ns	0.84 ns	1.88 ns	0.55 ns
H × D × E × S	6	3.09**	1.23 ns	1.72 ns	1.05 ns	0.56 ns	0.74 ns	0.06 ns	1.15 ns	0.63 ns	0.97 ns	0.26 ns

Harvested fruit were quarantine heat-treated (H) in the lab and subjected to ethanol vapors (E) 4 or 7 d after HW treatment (D) before cutting. Cut mangoes were stored 15 d at 7 °C (S). ns: not significant.

* Significant at $P < 0.05$.

** Significant at $P < 0.01$.

*** Significant at $P < 0.001$.

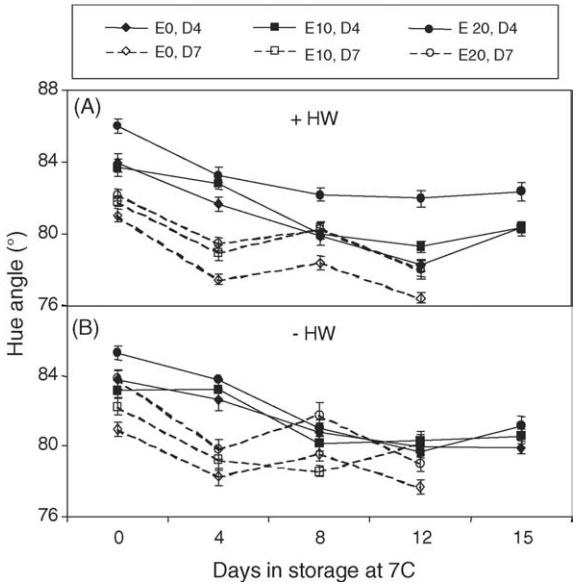

Fig. 2. Fresh-cut 'Kent' mango hue angle over time in storage at 7 °C. Whole mangoes were first subjected to a quarantine hot water treatment (+HW, A) or not treated with HW (−HW, B), then treated with ethanol vapors for 0 (E0), 10 (E10) or 20 (E20) h, at two ripeness stages, 4 d (D4) or 7 d (D7) after HW treatment. Each point is the mean of 30 measurements (10 measurements per replication, 3 replications), with standard errors.

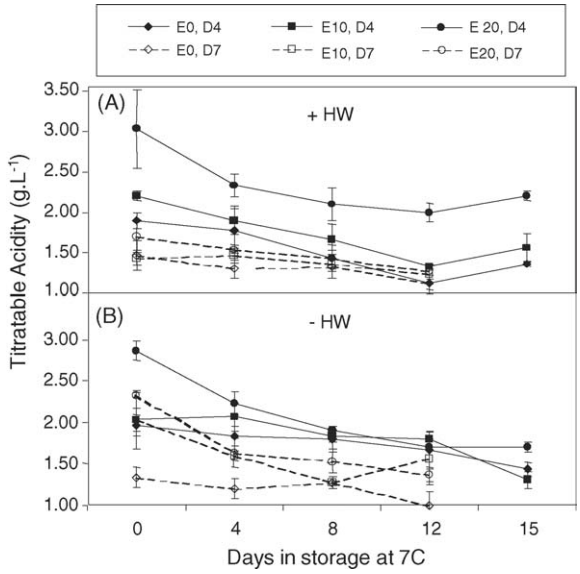

Fig. 3. Fresh-cut 'Kent' mango titratable acidity (TA) over time in storage at 7 °C. Whole mangoes were first subjected to a quarantine hot water treatment (+HW, A) or not treated with HW (−HW, B), then treated with ethanol vapors for 0 (E0), 10 (E10) or 20 (E20) h, at two ripeness stages, 4 d (D4) or 7 d (D7) after HW treatment. Each point is the mean of three replications, with standard errors.

E20-treated fruit (D4 and D7), and E0-D4 had firmness above 6.5 N (Fig. 1B). In storage, D4 fruit tended to maintain a higher firmness.

For fresh-cut mangoes, a lower L^* may be an indicator of flesh browning (Chantanawarangoon, 2000), an increase in a^* indicates flesh becoming more red/orange and a higher b^* more yellow (González-Aguilar et al., 2000). Therefore, a decrease in hue angle in stored fresh-cut mango indicates flesh that turns from light yellow to orange/red. Hue angle was generally higher for fruit ethanol-treated at D4 relative to those treated at D7 (Fig. 2A and B). Mango slices from +HW-D4-E20-treated fruit had the highest hue angle (Fig. 2A) and L^*-value (data not shown) during the whole storage period. For +HW-D7 fruit, both ethanol exposure times (E10 and E20) resulted in higher hue angle than E0 (Fig. 2A). Fruit subjected to E20 in the −HW group had higher hue angle only initially (both ripeness levels), and after 8 d (D7) or 15 d (D4) in storage (Fig. 2B). In spite of differences between ripeness levels with the instrumental measurements, visual quality was mostly higher only for the +HW-D4-E20-treated fruit (data not shown).

As with color and firmness, TA of fresh-cut mangoes was initially higher in + and −HW-D4-E20-treated fruit (Fig. 3); TA remained high in storage for the +HW-D4-E20-treated mangoes (Fig. 3A). The TA tended to be lower for D7 than D4 fruit in both +HW and −HW pre-treated fruit, with exception of some initial values (Fig. 3B), and after 12 d in storage (Fig. 3A). The TA was lowest for E0 in both +HW and −HW groups, D7, except after 8 d in storage for −HW-D7 (Fig. 3B).

Ethanol and acetaldehyde were highest in + and −HW-D7-E20-treated fruit (Figs. 4 and 5). Conversion of ethanol to acetaldehyde as described by Beaulieu et al. (1997) was mostly seen in +HW-D4 and D7, and E20-treated fruit:

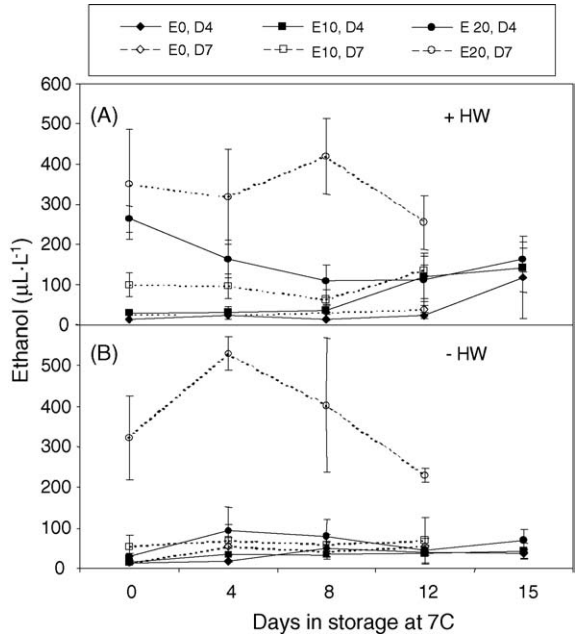

Fig. 4. Fresh-cut 'Kent' mango ethanol content over time in storage at 7 °C. Whole mangoes were first subjected to a quarantine hot water treatment (+HW, A) or not treated with HW (−HW, B), then treated with ethanol vapors for 0 (E0), 10 (E10) or 20 (E20) h, at two ripeness stages, 4 d (D4) or 7 d (D7) after HW treatment. Each point is the mean of three replications, with standard errors.

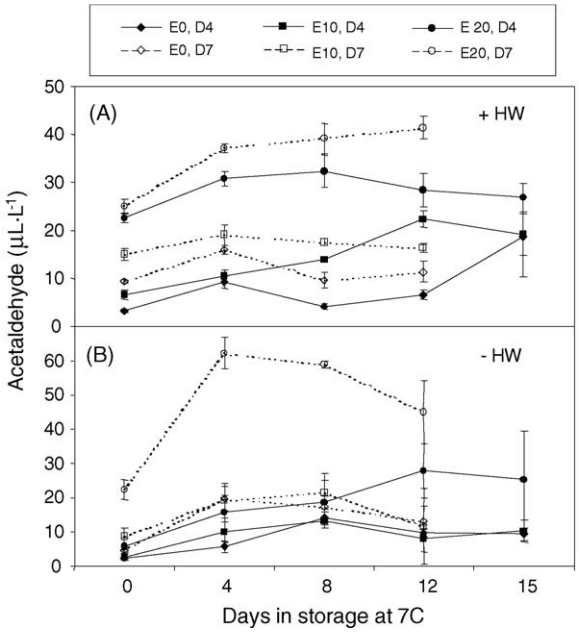

Fig. 5. Fresh-cut mango acetaldehyde content over time in storage at 7 °C. Whole mangoes were first subjected to a quarantine hot water treatment (+HW, A) or not treated with HW (−HW, B), then treated with ethanol vapors for 0 (E0), 10 (E10) or 20 (E20) h, at two ripeness stages, 4 d (D4) or 7 d (D7) after HW treatment. Each point is the mean of three replications, with standard errors.

ethanol decreased and acetaldehyde increased in storage, except at 8 d (+HW-D7-E20), and 15 d (+HW-D4-E20) (Figs. 4A and 5A). The increase of internal ethanol in fresh-cut mangoes from the +HW-D4 group between 12 and 15 d in storage (Fig. 4A) reflects over-ripening (Bender et al., 2000). In fact, fruit in the + or −HW-D7 group were not measured at that late date because of degradation and loss of structure.

CO_2 production rate in fresh slices ranged 5.18–12.71 $\mu g\,kg^{-1}\,s^{-1}$. There were no differences between treatments, except for +HW-D7 fruit 4 and 8 d in storage: control slices, +HW-D7-E0 had higher respiration rate (7.48 $\mu g\,kg^{-1}\,s^{-1}$) than +HW-D7-E10 and E20 (5.57 and 5.18 $\mu g\,kg^{-1}\,s^{-1}$, respectively) 4 d in storage, and +HW-D7-E0 and +HW-D7-E10 had higher respiration rates than +HW-D7-E20, 8 d in storage (6.00 $\mu g\,kg^{-1}\,s^{-1}$ for E-20, versus 8.78 and 8.35 $\mu g\,kg^{-1}\,s^{-1}$ for E-10 and E-0, respectively).

Ethylene was not detected in any of the samples measured. Burdon et al. (1996) pointed out the low level of ethylene produced by mango discs. These authors were only able to show the acetaldehyde inhibiting effect on ethylene production by feeding tissue with exogenous ACC to induce ethylene.

3.1.3. Sensory analysis

Ranking tests were performed as they were shown to give similar results to scaling tests, and are easier to perform when time for training a panel is limited (Rodrigue et al., 2000). Fruit subjected to E20 at D4, both +HW and −HW, were the least preferred, had the highest firmness except for −HW-D4-E20, had the highest tartness and lowest mango flavor (Table 3A).

When the ethanol treatment for 10 h (E10) was compared to the control (E0) in the D7 group, with both +HW or −HW pre-treatments, differences between treatments were much less detectable by panelists. On the day of cutting (day "0"), mangoes that had been exposed to E10 were ranked higher for firmness and tartness than E0, in both + and −HW pre-treated fruit (Table 3B).

3.2. Experiment 2: store-purchased mangoes

In contrast to the harvested mangoes, the store-purchased mangoes exposed to 20 h of ethanol vapor (E20) absorbed about twice the amount of ethanol than those exposed for 10 h (E10) (Table 1).

3.2.1. Fruit quality

F-values were much higher for storage than treatment effect for firmness, L^*, hue angle, SSC, TA and pH (Table 4). Treatment effect (ethanol or VH) was significant at $P < 0.05$ only for firmness and hue angle. On the other hand, acetaldehyde, ethanol, methanol, and β-pinene in fresh-cut fruit responded with a high level of significance ($P < 0.001$) to the treatment effect (Table 4).

Firmness, L^*, hue angle, SSC and TA decreased in storage, and pH increased (Table 4). Within storage periods, firmness was higher in ethanol-treated fruit, 13 d in storage. L^* was higher in ethanol-treated fruit stored for 13 d, indicating lighter fruit, but there were no differences in hue angle. Initially, SSC was lower in E20-treated fruit than control, and TA was higher but not significantly, while VH-treated fruit had lower acidity than E20. However, after 7 and 13 d in storage there were no differences for SSC, TA, or pH (Table 4).

Acetaldehyde, ethanol, methanol, and β-pinene were found at the highest levels in E20-treated fruit, and the least amount in control and VH-treated fruit, initially. In storage, differences were less, mostly because those volatiles increased in stored control fruit; also, VH-treated fruit had high ethanol content after 7 d in storage (Table 4). The level of internal ethanol in E20-treated fruit in this experiment was initially similar to that of +HW-D4-E20-treated fruit in the first experiment, but the E10-treated mangoes had higher internal ethanol in the second experiment than in the first.

The sensory panel did not detect any differences between treatments in this experiment. Some off-flavor was reported in ethanol-treated fruit, mostly those treated for 20 h, but also for 10 h, as well as in VH-treated fruit. Comments were "fermented", "overripe", "grape", "musty", "paper", and one panelist described the E20-treated sample as "greener".

Table 3
Mean ranks for 'Kent' mango slice sensory descriptors evaluated by a panel of 16–18 members after 0 and 6 d in storage

Days in storage	Treatments[a]		Descriptors[b]				
			Overall preference	Firmness	Tartness	Mango flavor	% Off-flavor
(A) Ethanol applied 4 d after hot water treatment (D4)							
0	+HW						
		E0	2.20 a	1.73 b	1.73 b	2.20 a	33.3
		E10	2.53 a	1.47 b	1.73 b	2.47 a	20.0
		E20	1.27 b	2.80 a	2.53 a	1.33 b	60.0
		α-Level	0.01	0.01	0.05	0.05	
6	+HW						
		E0	2.31 a	1.62 b	1.36 c	2.27 a	19.2
		E10	1.88 ab	1.96 ab	2.00 b	2.15 a	38.5
		E20	1.81 b	2.42 a	2.64 a	1.58 b	42.3
		α-Level	0.25	0.05	0.05	0.05	
6	−HW						
		E0	2.08 a	2.04	1.69 b	2.08 ab	23.0
		E10	2.50 a	2.08	1.85 b	2.35 a	19.2
		E20	1.42 b	1.88	2.46 a	1.58 b	61.5
		α-Level	0.05	ns	0.05	0.05	
(B) Ethanol applied 7 d after hot water treatment (D7)							
0	+HW						
		E0	2.65	1.75 b	2.06 b	2.31	31.2
		E10	2.63	3.31 a	3.13 a	2.38	62.5
	−HW						
		E0	2.35	2.19 b	2.19 b	2.63	37.5
		E10	2.47	2.75 ab	2.63 ab	2.69	31.2
		α-Level	ns	0.01	0.1	ns	
6	+HW						
		E0	2.33	2.60	2.25	2.33 b	50.0
		E10	2.20	2.20	2.81	2.13 b	37.5
	−HW						
		E0	2.80	2.80	2.38	3.07 a	31.2
		E10	2.67	2.40	2.56	2.47 ab	37.5
		α-Level	ns	ns	ns	0.25	

[a] Whole mango treatments prior to cutting were hot water (+ or −HW) treated and exposed to ethanol vapors for 0 h (E0), 10 h (E10) and 20 h (E20).
[b] Sums of ranks were analyzed with the Friedman statistic test. Means separation was done with the analog of the Fisher's LSD for rank sums, the level of significance is indicated by the alpha value in each column.

3.2.2. Microbial counts

Two types of media were used, PCA and PDA, to isolate a broader range of microorganisms, which gave very similar results (Table 5). Initial microbial populations on fresh-cut fruit samples from control, E10, and VH-treated fruit were approximately equivalent (Table 5). While there were fewer microorganisms on fresh-cut fruit pre-treated with E20, the difference was not significant. At the end of the first week in storage, control and VH-treated fruit showed an increase in microbial growth (7.4×10^6 and 1.8×10^7 cfu kg^{-1}, respectively), while pieces pre-treated with ethanol (E10 or E20) were significantly lower in microbial counts (4.8×10^4 and 2.5×10^4 cfu kg^{-1}, respectively) than either control or the VH treatment. At the end of the 15-d shelf life period, the VH-treated fruit samples had the highest microbial count (3.2×10^7 cfu kg^{-1}). Counts on E10 or E20 fruit increased from the previous week; the counts on control fruit decreased from the previous week, but not significantly.

4. Discussion

4.1. Effect of ethanol pre-cut treatments on ripening of mango slices

Exposing whole mangoes to ethanol vapors for 20 h prior to processing for fresh-cut only delayed ripening of harvested fruit that were prior heat-treated, and exposed to ethanol vapor at the RS3 ripeness stage (+HW-D4). Store-purchased fruit, also heat-treated through import procedures, did not respond to ethanol vapors with delayed ripening, even though they were ethanol-treated at the RS3–RS4 ripeness stage. Harvested mangoes not heat-treated but subjected to ethanol vapors for 20 h had indication of delayed ripening at the time of cutting (firmness, hue and acidity), but it did not last in storage.

RS3 was the maturity stage at which mangoes in the first experiment responded most to the ethanol treatment in the

Table 4
Fresh-cut 'Kent' mango quality parameters for store-purchased fruit: firmness, L^*, hue angle, soluble solids content (SSC), titratable acidity (TA), pH, acetaldehyde, ethanol, methanol and β-pinene[a]

Treatment	Days in storage	Firmness (N)	L^*	Hue angle	SSC (%)	TA (g L^{-1})	pH	Acetaldehyde (μL L^{-1})	Ethanol (μL L^{-1})	Methanol (μL L^{-1})	β-Pinene (nL L^{-1})
Control	0	10.06	68.32	84.02	9.13 a	2.30 ab	4.07	3.29 bc	13.12 c	3.16 c	0.0 c
E10	0	11.05	67.73	84.21	8.87 ab	2.45 ab	3.94	6.96 b	123.93 b	16.86 b	4.3 b
E20	0	9.37	67.33	84.27	8.40 b	2.63 a	4.04	12.24 a	292.12 a	37.30 a	8.3 a
VH	0	9.93	68.82	83.96	8.73 ab	1.97 b	4.09	2.89 c	16.17 c	3.39 c	2.0 bc
Mean		10.10 A	68.05 A	84.12 A	8.78 A	2.24 A	4.04 C	6.62	120.26	16.27	4.0
Control	7	7.62 a	61.96	81.57	8.87	2.03	4.22	3.69 b	68.48 b	5.78 b	0.0 b
E10	7	6.97 a	63.29	82.44	8.33	1.88	4.31	6.07 ab	143.00 ab	55.26 a	14.0 a
E20	7	7.64 a	61.86	80.83	8.60	2.03	4.17	8.85 a	268.98 a	54.10 a	12.0 a
VH	7	5.76 b	60.49	80.13	8.40	1.80	4.26	5.73 ab	130.69 ab	8.73 b	3.3 b
Mean		7.00 B	61.90 B	81.24 B	8.55 AB	1.93 B	4.24 B	6.09	153.68	28.76	6.7
Control	13	6.14 b	59.96 b	80.92	8.20	1.69	4.35	4.83 b	88.90 b	25.10 b	2.7 b
E10	13	7.00 ab	63.32 a	81.15	8.43	1.61	4.39	6.75 b	84.16 b	22.68 b	6.7 ab
E20	13	7.61 a	62.33 ab	80.58	8.10	1.66	4.36	14.03 a	310.49 a	77.09 a	12.3 a
VH	13	6.20 b	59.91 b	79.79	8.27	1.51	4.40	3.63 b	35.62 b	9.63 b	1.3 b
Mean		6.74 B	61.38 B	80.61 B	8.25 B	1.62 C	4.38 A	7.31	129.79	33.63	5.7

Source of variation	d.f.	ANOVA F-value									
Treatment (T)	3	2.79*	1.69 ns	3.26*	1.18 ns	2.26 ns	0.39 ns	22.17***	20.84***	19.78***	27.43***
Storage (S)	2	63.18***	56.66***	50.60***	9.27**	35.99***	47.29***	0.91 ns	0.81 ns	4.92*	4.70*
T × S	6	2.50*	1.57 ns	0.84 ns	0.62 ns	0.93 ns	0.55 ns	1.59 ns	0.96 ns	2.34 ns	2.52 ns

Treatments prior to cutting were ethanol vapor for 0 h (control), 10 h (E10), and 20 h (E20), and heat vapor (VH). F-values from ANOVA for each quality parameter at the bottom of the table indicate significant factors: treatment (T), storage (S), or interaction treatment × storage (T × S).

[a] Mean separation in a column by LSD test, $\alpha = 0.05$. Separation within and between "days in storage" are indicated by lower case and capital letters, respectively.

+HW pre-treated group, but in the second experiment, store-purchased ethanol-treated mangoes at the same RS3–RS4 stage did not respond. Beaulieu and Saltveit (1997) found that tomatoes were more sensitive to ethanol or acetaldehyde vapors as they were closer to their ethylene climacteric. The climacteric phase may initiate the promotion of many ripening-related enzymes, which have the potential to be directly inhibited by acetaldehyde (Mitcham and McDonald, 1993). The hot water treatment in Florida-harvested fruit (+HW fruit) initiated some ripening events, as observed on whole mangoes before cutting, which made these fruit more responsive to ethanol treatments, especially when the interval between the hot water and ethanol treatments was closer (fruit more responsive to high level of ethanol when treated at D4 than D7). In the case of store-purchased mangoes, time between quarantine heat treatment and ethanol treatments was unknown, so was temperature during storage and transport. Therefore, the physiological condition of store-purchased fruit at the time of ethanol exposure was unknown, but resulted in a lack of response to ethanol.

Mangoes exposed to ethanol vapors had high internal ethanol and acetaldehyde concentrations. However, there did not seem to be a direct relationship between ethanol concentration in the tissue and delayed maturity response, since the high amount of ethanol, and resulting acetaldehyde, in D7-E20-treated fruit (+ or −HW) and in store-bought fruit did not result in delayed ripening. On the other hand, high ethanol in +HW-D4-E20-treated fruit did result in delayed ripening. It is possible that there was a residual effect from the heat treatment in the +HW-D4-E20-treated mangoes, in addition to the direct effect of ethanol on these fruit, as discussed above. Ripening inhibition due to heat, mostly through decrease in

Table 5
Microbial counts (cfu kg^{-1}) in potato dextrose agar (PDA) and plate count agar (PCA) media of fresh-cut store-purchased 'Kent' mangoes after treatments and stored 15 d at 7 °C ($n = 9$)[a]

Days in storage	Treatment	PDA (cfu kg^{-1})	PCA (cfu kg^{-1})
0	Control	1.0×10^5	1.8×10^5
	E10	7.0×10^3	2.8×10^5
	E20	7.0×10^3	1.8×10^4
	VH	9.8×10^4	1.0×10^5
		ns	ns
7	Control	7.5×10^6	7.3×10^6
	E10	8.7×10^4	8.0×10^3
	E20	6.0×10^3	4.2×10^4
	VH	1.9×10^7	1.7×10^7
		**	**
15	Control	2.4×10^6	3.7×10^6
	E10	1.4×10^5	1.6×10^5
	E20	1.4×10^5	1.8×10^5
	VH	2.3×10^7	4.1×10^7
		**	*

Significance between treatments and within media indicated in each cell. Significance within column by the non-parametric Savage one-way analysis. ns: not significant.

[*] Significant at $P < 0.05$.

[**] Significant at $P < 0.01$.

ethylene production, is usually reversible, but it may last 3–5 d (Mitcham and McDonald, 1997; Ketsa et al., 1999; Jacobi et al., 2001).

Beaulieu and Saltveit (1997) demonstrated, by using an alcohol dehydrogenase inhibitor, that ripening inhibition in tomato discs was due to the effect of acetaldehyde more than ethanol. In fact, ethanol vapor (1% for 4 h) was found to enhance ethylene production in mango discs, but acetaldehyde at the same concentration had an inhibiting effect due to direct inhibition of ACC oxidase (Burdon et al., 1996). Beaulieu and Saltveit (1997) explained that at low concentrations, ethanol or acetaldehyde could promote synthesis of ACC, while at higher concentration, ACC oxidase was inhibited, therefore reducing ethylene production. In the present study, it appears that acetaldehyde and ethanol were above a level at which they would have either enhancing or inhibiting activity on ripening events in fruit exposed to E20 at D7 (+HW and −HW), and in store-purchased E20-treated mangoes. The higher hue angle of +HW-D7-E10- or +HW-D7-E20-treated fruit with respect to the control (Fig. 2A) could be explained by a direct inhibitory effect of acetaldehyde on enzymatic as well as non-enzymatic browning (Burdon et al., 1996).

The high amount of ethanol measured in fruit exposed to E20 did not reflect the amount of ethanol absorbed by the fruit in the first experiment (Table 1). In other words, for harvested mangoes, ethanol absorbed for 20 h was not twice the amount of ethanol absorbed for 10 h (Table 1), and ethanol in fruit exposed for 20 h was much higher than in fruit exposed for 10 h, up to 10 times higher for +HW-D4-ethanol-treated fruit (Fig. 4A). In contrast to the harvested mangoes, the store-purchased mangoes exposed to 20 h of ethanol vapor (E20) absorbed about twice the amount of ethanol than those exposed for 10 h (E10) (Table 1), and resulting internal ethanol was about twice as much in E20 than in E10 (Table 4). Ethanol had a pattern similar to autocatalytic production in + and −HW-D7-E20-treated fruit, and +HW-D4-E20-treated fruit, while in contrast, internal ethanol in store-purchased mangoes seemed to be the result of passive absorption. The atmosphere in the containers was measured for two sets of fruit (+ and −HW-D4) to verify the absence of an anaerobic atmosphere. Gas composition was 17 kPa O_2 and 2 kPa CO_2 after 20 h, which would not be expected to induce anaerobiosis or CO_2 injury. Mangoes can tolerate atmospheres of 25 kPa CO_2 with 3–5 kPa O_2 (Bender et al., 2000), and recommended controlled atmosphere for mango is 5–8 kPa CO_2 and 3–7 kPa O_2 (Kader, 2002).

4.2. Sensory evaluation

When three samples were presented to the panelists, they could discriminate between firmer and more acid fruit (Table 3A) and found same differences as those measured instrumentally for firmness and TA (Figs. 1 and 3). However, when presented with four samples, and asked to rank for intensity of firmness, tartness and mango flavor, panelists could discriminate between E0 and E10 fruit (both + and −HW) on day of processing fruit (Table 3B). Firmness and tartness were ranked highest for E10 fruit in comparison with E0, but there were no differences between + or −HW-E0 and + or −HW-E10 in instrumental firmness 0 d in storage (Fig. 1), TA (Fig. 3), or SSC or pH (data not shown). The lack of correspondence between firmness measurements with the texture analyzer and sensory data indicates that changes in the mango texture perceived by chewing were not related to compression by a 10 mm probe.

The low rankings for preference and mango flavor for E20-treated fruit (+ and −HW-D4, 0 and 6 d in storage, Table 3A) could be explained by a high percentage of samples with reported off-flavor, described as “overripe”, “fermented”, “grape”, and “cardboard”. Ethanol and acetaldehyde were much higher in the +HW-D4-E20-treated fruit, but not in the −HW-D4-E20 group (Figs. 4 and 5). Methanol too was significantly higher (107.5 and 108.4 $\mu L\,L^{-1}$, 0 and 4 d in storage, respectively) in the +HW-D4-E20-treated fruit, than in +HW-D4-E0 and -E10 (104.5 and 103.9 $\mu L\,L^{-1}$ in both E0 and E10, 0 and 4 d in storage, respectively). There were no differences between ethanol treatments in the methanol levels of −HW-D4 fruit (data not shown). Therefore the off-flavor reported in all the fruit exposed to 20 h ethanol is not completely due to the high levels of ethanol, acetaldehyde and methanol, but also to other flavors not detected in the current method of analysis. We analyzed mango volatiles by direct headspace, which cannot detect some volatiles that require concentration for detection, but may be important for the fruit flavor. The level of β-pinene, a possible off-flavor in mango fruit, was not significantly different between ethanol exposures for +HW-D4-treated fruit.

4.3. Microbial analysis

Microbial populations were only evaluated in the second experiment. The unusually high numbers in VH-treated fruit compared to the control samples, could be attributed to damage to the fruit tissue during heating resulting in electrolyte leakage (Mitcham and McDonald, 1997), which may have allowed for more easily available nutrients. The higher microbe numbers in VH-treated and control fruit could have contributed to the lower L^*-value (i.e., darker fruit surface; Table 4). Even though the fresh-cut mango tissue had no direct contact with ethanol, either the internal ethanol (or acetaldehyde) in ethanol pre-treated fruit was responsible for the lower microbial count, or the ethanol treatment changed the fruit tissue to the point of making it more resistant to microbial growth. However, the physiological changes measured in this experiment in the ethanol groups were not different from the control (Table 5), therefore less cross-contamination from the peel during processing, or internal ethanol and acetaldehyde are prominent contributing factors to the low microbial counts.

5. Conclusion

This paper concludes a series of experiments that explored the possibility of the use of pre-treatments with ethanol vapor or vapor heat (38 °C and >98% RH air) on whole mangoes to extend shelf life of fresh-cut slices. Exploratory tests determined that ethanol vapors applied for 24 h were effective in extending fresh-cut 'Kent' shelf life, but were detrimental to flavor, while 8 h of exposure, although not detrimental to flavor, did not have a significant effect on storage (Plotto et al., 2003). In those earlier studies, as well as in the second experiment reported herein, the quarantine HW treatment to which imported mangoes are subjected presents a confounding factor to understanding experimental results. In the experiment with Florida mangoes, a HW bath simulating a quarantine treatment was applied 2 d after harvest, and mangoes were exposed to ethanol vapors at different stages of ripeness. The quarantine heat treatment synchronized mango ripening. Only +HW-treated mangoes responded positively to a long exposure (20 h) of ethanol vapors, especially those exposed at the ripeness stage RS3 (D4 fruit). Results suggest that the HW treatment initiated activity in ripening-related enzymes, and ethanol, or acetaldehyde resulting from ethanol treatment, inhibited some of these enzymes. The inhibition effect was more pronounced when mangoes were ethanol-treated sooner after the HW treatment (D4 versus D7).

Practically, ethanol vapors could not be used on mangoes to extend fresh-cut shelf life because of the development of off-flavor when exposed to more than 20 h, and the non-reproducibility of the results when applied at lower dosage is confounded by harvest maturity and heat treatment. Nevertheless, at lower application rates (8–10 h exposure), ethanol could be used as a safe microbial control in a fresh-cut production sanitation system. We confirmed that an additional heat treatment (38 °C and 98% RH air) was detrimental to quality and microbial stability of fresh-cut mango slices in storage.

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